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Train Collision Avoidance System: A Technological Survey

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Abstract: With the growing demand for railway traffic, both in terms of Passenger and freight transportation, the traffic density has increased, sometimes exceeding the line capacity on busy routes. However, the signalling system has been advanced through high-end EI (electronic interlocking) for the safest movement of trains. Nevertheless, the safety of trains at higher speeds may be compromised due to the dependency on human interaction between crew members (engine drivers) and ground staff (station controllers). Excessive human dependence may result in SPAD (Signal Passed at Danger), head-on collisions, rear-end collisions, or side collisions involving high-speed trains. The objective of this study is to analyse an additional layer of train protection that can automatically stop the train before an incident occurs, without requiring human interaction. The aim of this paper is to study the complexity of this system through a technological survey of various systems, including AWS (Automatic Warning System), ACD (Anti-Collision Device), TPWS (Train Protection and Warning System), TCAS (Train Collision Avoidance System) and finally ATP (Automatic Train Protection System). The paper also summarizes technological upgradation in accordance with various international standards, including ETCS (European Train Control System), SIL (Safety Integrity Level), CENLEC (European Committee for Electrical Standardization), and ETSI (European Telecommunication Standards Institute). ERTMS (European Rail Traffic Management System) is a European Union-mandated framework for interoperable and safer railway signaling and control. Section I provides an overview of the literature review background for technical papers on train protection with moving block and virtual coupling. The concept of Virtual Coupling advances Moving Block operations by reducing train separation to less than the standard braking distance, utilizing Train-to-Train RF communication. The system also mutually exchanges dynamic information (e.g., location, speed, acceleration) and trains can be separated by a relative braking safe distance of a train behind the train. Section II provides an introduction and development of TCAS generations, including the upgradation or inclusion of technology, and Section III summarizes the basic functions of TCAS. Section IV: RFID Tag and making of TIN layout details, Section V: Introduces NMS. Section VI gives insight into the Establishment of communication. Section VII provides the initiation of radio Communication. Sections VIII & IX focus on the Conclusion and Future Scope.

Introduction

The objective of this study is to analyse the technological advancement and growth in the safety of train operation through a literature review provided in this section. High-speed train operation is necessary for optimal utilization of the section's capacity (Line capacity). High-speed trains are also required to compete with other modes of transportation in order to meet

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customer requirements. Figure 1 below presents a comparative study of the operating speeds of trains worldwide.

The moving block concept and virtual coupling have been studied in (Aoun et al., 2020; Aoun et al., 2021; Aoun et al., 2022; Aoun et al., 2023). A hazardous analysis of the moving block has been studied in (ASTRail, 2019). A The reinforcement learning control of virtual coupling has been explored in (Basile et al., 2022). A dynamically connected system provides an eternal networked software system (Bertolino et al., 2011). The modelling tool for the dynamic moving block has been developed using Petri Net models (Clark et al., 2001; Courtney et al., 2009). A traffic analysis of a tramway system with virtual tags and local positioning is developed through a stochastic modeling approach (da Silva et al., 2021). ETCS levels and modes were also reintroduced according to the technology of moving block and virtual coupling (Biagi et al., 2017; Europe's Rail, 2022; European Commission, 2023). The future train Control system has been studied with its dependence on the existing system (Fantechi et al., 2022). A predictive control approach for virtual coupling has been explored in the concept of closure running, as discussed in Fenner (2016), Felez et al. (2019) and Flammini et al. (2019). A compositional model of virtual coupling through a stochastic activity network may be used for a Train protection system with safety analysis using a fault tree and a Bayesian network (Flammini et al., 2021; Khakzad et al., 2011; Mahboob and Straub, 2011). Key performance indicators for the Railway ITS have been proposed for the moving block transport system (Mlinarić et al., 2018). Real-time traffic rescheduling algorithm for Hazardous prevention in a moving block system. A multi-state train model for virtual coupling has given the dynamic condition of the moving block (Quaglietta et al., 2020; Quaglietta et al., 2022). WSN-based information of train monitoring has been defined in (Sharma et al., 2024). GSM-R is escalated to FRMC, as provided in (Rail Engineer, 2023). Safety-critical railway systems have been extensively studied in various contexts (Rail Tech, 2022; Scheepmaker et al., 2020; Shubinsky et al., 2023). Futuristic Railway Mobile Communication using FRMCS is given in (UIC, 2023; UNISIG, 2019). A moving block safety analysis for an advanced signalling system is presented in (Di Meo et al., 2019; X2Rail-1, 2019; X2Rail-3, 2018; X2Rail-3, 2020). The modernized interlocking system for moving block is given in (Zafar et al., 2012). Table 1 below shows a comparison of train speed targets achieved worldwide.

Table 1. Train speed achieved worldwide.

Rank	Train Name	Country	Maximum Speed (km/h)	Maximum Speed (mph)
1	Shanghai Maglev	Chia	460	286
2	CR Harmony & CR Fuxing	China	350	217
3	Siemens Velaro E/AVs 103	Spain	400	249
4	TGV POS	France	357	222
5	CRH380A Hexie	China	302	188
6	Hemu-430X (China)	China	422	262
7	Fuxing Hao CR400AF/BF	China	400	249
8	Frecciarossa	Italy	394	245
9	Shinkansen H5 & E5	Japan	360	224
10	Deutsche Bahn ICE & Korail KTX	Germany &South Korea	330	205

The train operation is traditionally controlled with line-side signalling, in which the loco pilot observes the signal aspect unit mounted on the track-side signal post and thereby takes the most appropriate decision. The visibility time of the Train Driver reduces from 16 seconds at the speed of 90 kmph to 4.1 seconds at 350 kmph, assuming that the line-side signal aspects are visible for 400 meters. Figure 2 below shows the variation of the signal visibility period versus the Speed of the train.

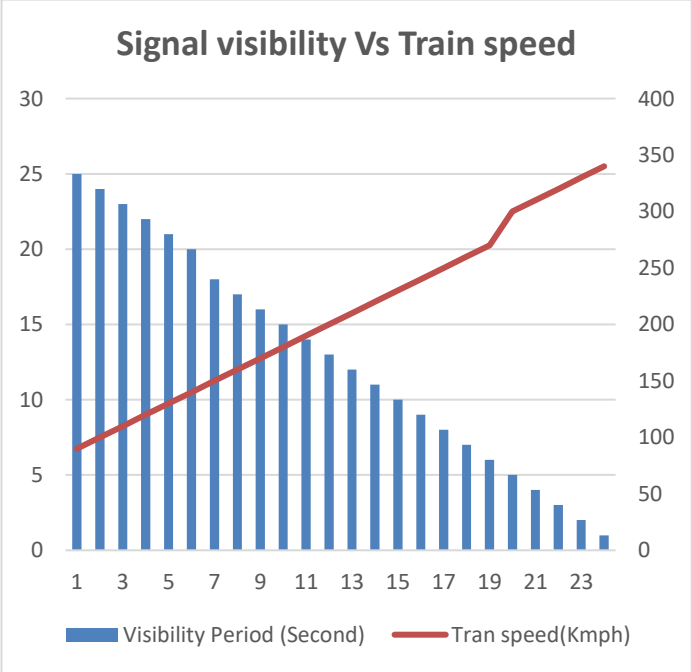

Figure 1. Signal Aspect visibility period in relation to the speed of the train.

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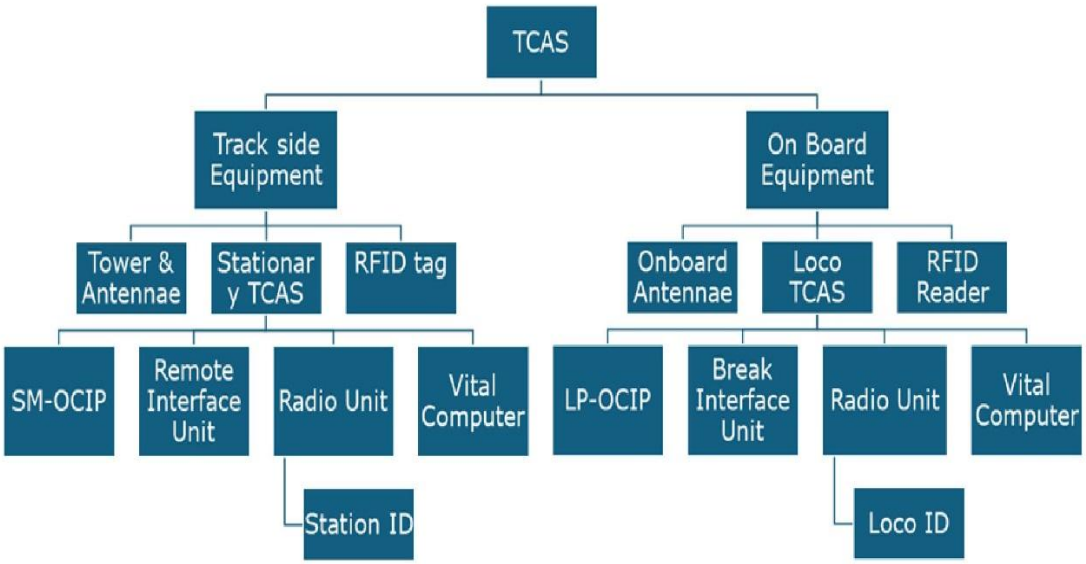

Figure 2. Basic Building block of TCAS (Kavach).

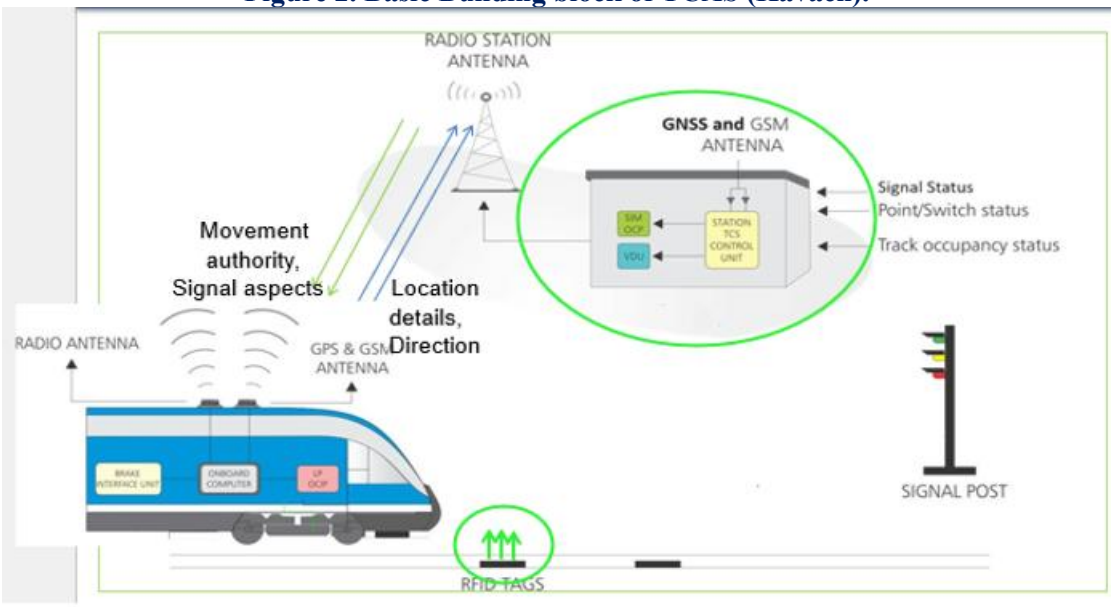

Figure 3. Functionality of TCAS.

According to the graph in Figure 2, the visibility period is insufficient at 140 KMPH, which may result in unusual incidents, such as SPAD. For trains running at speeds beyond 140 km/h, the ATP system with cab signalling is compulsory. Basic features of TCAS are

- Mitigation of SPAD, hence trains cannot pass the most restrictive aspect, i.e., danger due to the human fault of the driver.
- Continuous supervision of train speed.
- Displaying the aspect of an approaching signal in the Driver's cab along with Sufficient movement authority.
- Automatic blowing of the train horn while approaching the Level crossing gate.
- Prevention of Head-on Train Collision.
- Prevention of rear-end train collision.
- Prevention of Side train collision.
- It is a user-friendly DMI with cab signalling functions as a safety aid to the loco pilot, which will help train drivers in Foggy weather (when line signal posts are not visible) at high speed.
- Centralized monitoring of real-time train in the NMS (Network Management System) of TCAS.

#Materials and Methods

Figure 2 shows the basic building block of the TCAS system, comprising components and devices involved

#Functionality of KAVACH

The basic building block of TCAS is shown in Figure 4 below, where the Station TCAS is equipped with a GPS and GSM antenna, which fetches the station information in terms of Signal status, Point/switch status and Track Occupancy status. RF antenna to communicate with Loco TCAS at regular intervals. The Loco TCAS is also equipped with the same set of antennas, which provide

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Location details and direction based on RFID tags fitted on railway sleepers.

#TCAS data flow

Figure 5 below illustrates Stationary TCAS. The field-side data (Signal, Point, Track information) from the relay room or relay hut in the auto signal section is provided to the stationary TCAS through the interface unit, which is further connected with NMS, SM OCIP (Station Master Operation Cum Indication Panel), and Wireless data further communicates with LOCO with Radio LOCO antenna. The Loco TCAS continuously updates track-side information (Direction, Tag type, TIN, etc) through the RFID tag Reader. The Loco TCAS is further equipped with LP-OCIP (Loco Pilot Operation Cum Indication Panel) to provide movement authority, also to drive the BIU (Break interface unit) to apply the emergency brake automatically in case of unusual conditions.

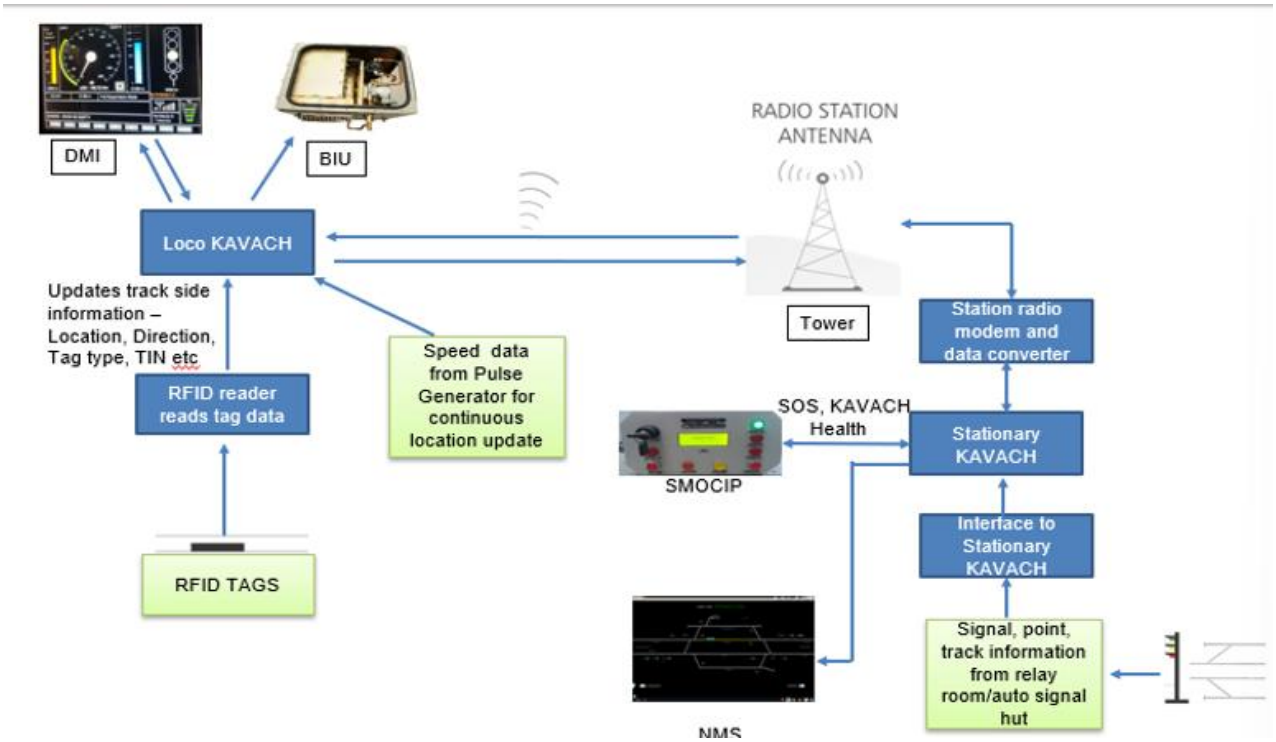

Figure 4. TCAS data flow.

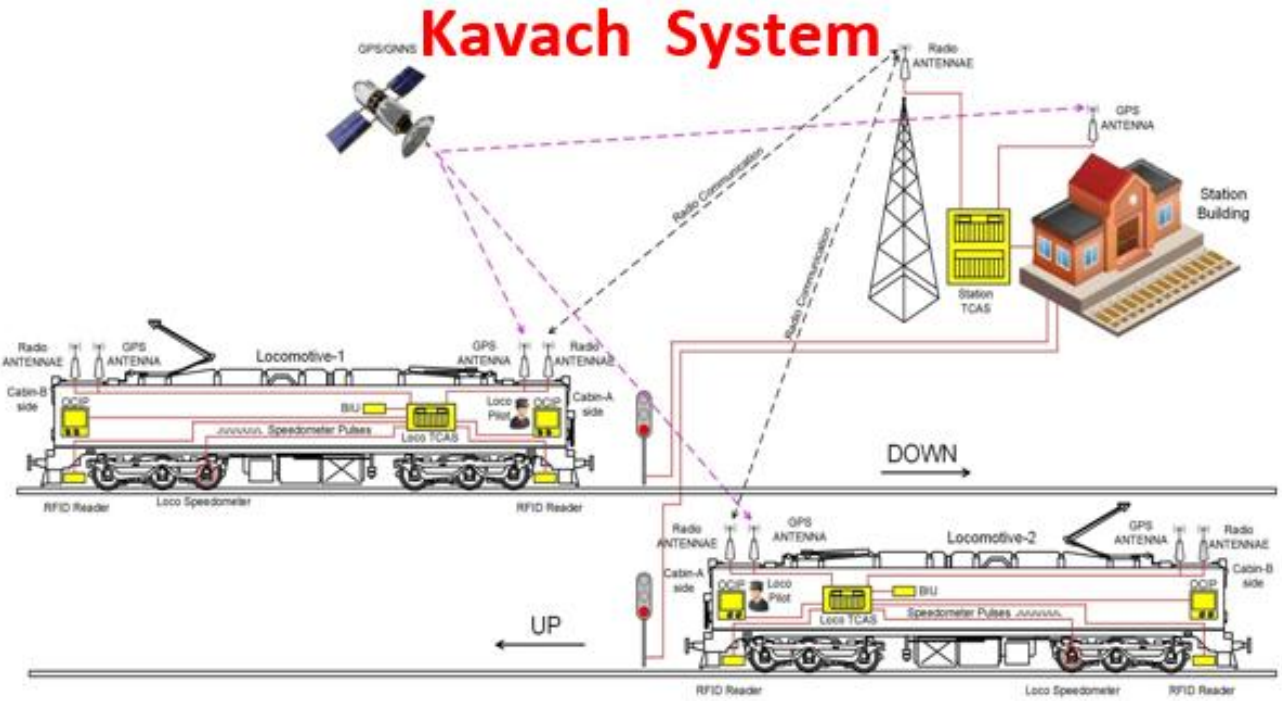

Figure 5. Working Model of TCAS.

Station Radio modem and data converter. The station Radio modem transfers information through the Station radio antenna fitted on a tower near the station. The

#Working model of TCAS

Figure 6 below illustrates the operation of the integrated TCAS system, which communicates between

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stations, stations and locomotives, and locomotives. A set of three types of antennas (RF, GPS & GSM) is installed on both entities, i.e., Station and Onboard Loco. With RF antennas, the Station Continuously pings with all the locos in its vicinity on a particular pair of Radio frequencies. However, Loco to Loco pinging also occurs in the block sections, where each updates the other's location. However, the SOS message is broadcast on dedicated frequencies. With the GSM antenna, the necessary authentication keys and messages are transmitted between the Station and the Loco. GPS antennas are especially accurate in their positions and are used for time synchronization.

#Functions of LP OCIP

Figure 7 below shows LP-OCIP (Loco Pilot-Operation Cum Indication Panel), which will provide all the necessary information from RFID tags and the stationary TCAS (Train Collision Avoidance System) to control the movement of authority on this panel (Kangmi et al., 2013; Patil, 2016; Fatima, M., & Aarti, 2023; Atul, 2024; Mahesh et al., 2025).

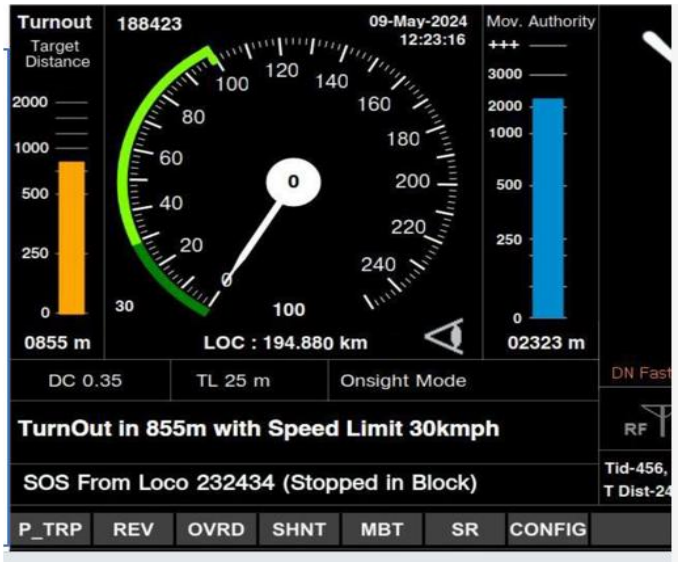

Figure 6. LP-OCIP (Loco Pilot Operation Cum Indication Panel).

This Onboard panel will provide information like, Target type and Distance, Loco ID, Date and Time, All categories of speed to be controlled (Permitted speed, current speed, PSR speed, Sectional speed, Turnout speed), Location of the train, Brake application symbol, Sginal aspect, distance, Deacceleration constant, Train length, Operating mode symbol & text, RF communication with station, RFID number, direction of travel, Next RFID Tag distance, RFID reading status, Green/red, Selection of soft keys.

#RFID tag implantation and TIN selection

RFID tags shall be fixed at the center of PSC (Sleepers) (Olaby et al., 2024). No holes shall be drilled in the Sleepers, and the arrangement of fixing must be through clamps only (Tanaka et al., 2023). Shall be able to work even when submerged in water up to rail level. Figure 8 below shows the fixing of the RFID tag on the Rail sleepers.

Figure 7. Fixing the RFID tag on the Rail sleeper.

The following information is fetched from the RFID tag-

- Tag ID, Type, Version, Absolute Location.
- TIN, Station ID, Section Type, Communication Required in Nominal/Reverse Direction.
- Main/Duplicate Tag
- LC Gate Tag (Gate ID, Manned/Unmanned, Distance, Auto whistling)
- Adjacent Line Tag (TIN of Lines up to 5)
- Adjustment/Junction Tag (TIN, Absolute Location and Direction correction details)
- RFID Tags shall be fitted on the track in the station section as well as in the block section to transmit information to the Loco KAVACH unit directly.
- RFID Tags are duplicated and transmit the same information.
- Each Loco KAVACH unit shall have two RFID READERS
- When the Loco KAVACH unit RFID reader passes over the RFID tag, the RFID tag shall transmit the programmed data to the RFID reader.
- Loco unit shall act as per the information received from even one RFID tag out of duplicated tags.
- RFID Tags contain Absolute Location information, therefore, it removes odometry errors (due to slip/slide, wheel dia, etc).
- If three consecutive Normal RFID tags are not read, Loco KAVACH shall switch from Full Supervision (FS) mode to Staff Responsible (SR) mode.

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- If Loco KAVACH unit reads the KAVACH exit tag (non-KAVACH territory), it shall stop the radio communication and shall switch to Staff Responsible mode.
- On start-up or restart, the Loco Kavach shall assume movement direction as undefined. When Loco Kavach has read two RFID tags, the Direction will be set as Nominal/Reverse.
- If the Absolute location value is incrementing, it shall be treated as Nominal direction. If the Absolute location is decreasing, it shall be treated as a Reverse direction.

RFID Tags Classification

The RFID tags are classified into various categories depending upon their applications and the position where these tags are to be placed on the railway track, as summarized below.

#Normal Tag (N/S/T)

Normal Tag is placed in the station yard and block section as shown in Figure 9. Normal tags shall be provided in the block section as well as in the station section.

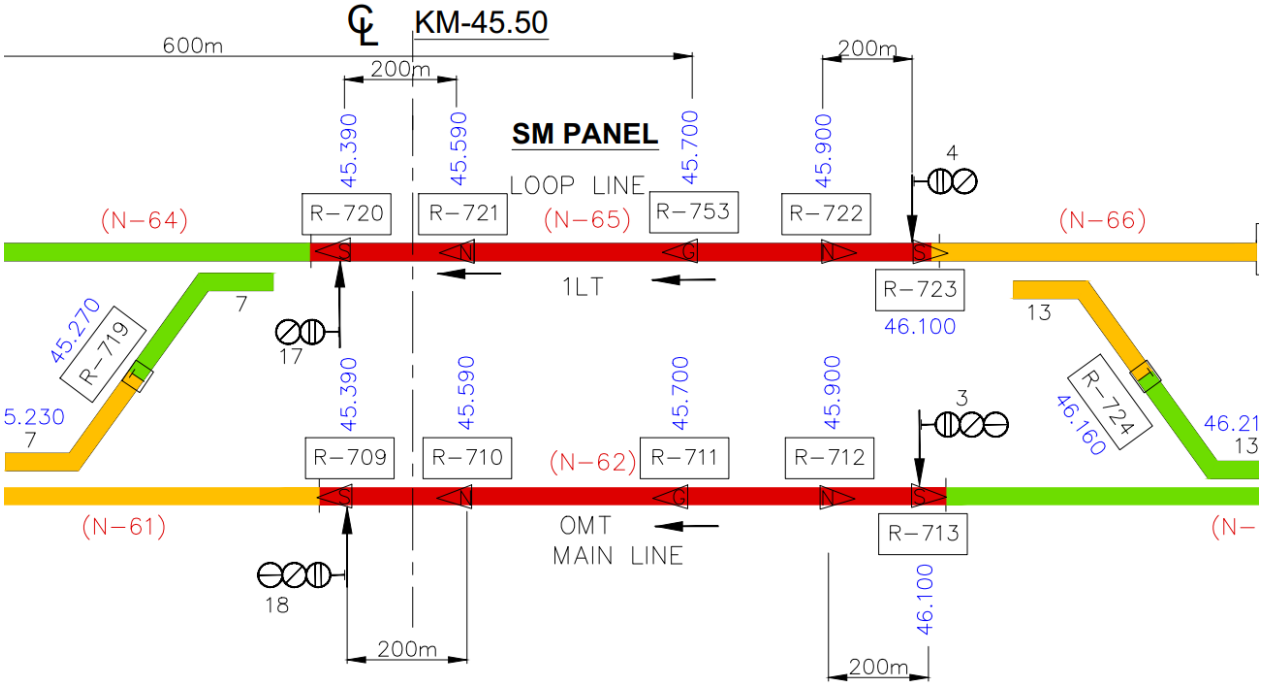

Figure 8. Normal Tag in the yard.

- The maximum distance between the two normal tags shall not be more than 1000m in the Block Section. Signal foot tags shall be provided at the foot of every signal post.

Every Main signal, Subsidiary signal, stop board, End of berthing track, and BSLB shall be provided with a Signal foot tag. Turnout tags will be placed at turnouts.

Border ID Tag (N)

Border Tags are placed in a block section to identify the boundary between two Stationary Kavach communication zones. Border RFID tags shall be indicated in the RFID Tag layout with the absolute location of the station border line. After crossing the Border RFID tag, the loco shall communicate only with the next stationary SKAVACH.

Exit tags

Placed on the boundary between a TCAS-fitted and a non-TCAS area. The Exit Tag (X) is used for exiting from the Kavach-fitted area to the unfitted area. Min 2 Tags are installed at 10 m apart. Transit to SR mode. Stop the communication after the complete train passes over. It defines the transition from KAVACH to non-KAVACH territory. Minimum 2 sets of Tags shall be provided as Exit tags. The 1st Exit RFID shall be programmed with Communication in Direction of entry & no communication in direction of exit and 2nd Exit Tag shall be programmed with no communication required in both directions. Exit tags are provided at a distance of not less than 10m.

Adjacent Line Tag

These RFID tags are placed in a block section to give information about adjacent line(s). An adjustment/Junction tag shall be provided, wherever required, to adjust the absolute location in the block section and at junction stations to correct the absolute location. The Absolute Location-1 shall be taken as the physical location in the direction of travel, and Absolute Location-2 shall be taken as the corrected absolute location. Direction Correction-1 shall be taken as the physical direction of onboard travel, and Direction Correction-2 shall be taken as the physical direction after reading the adjustment tag.ABS-1 is the physical location after the RFID Tag R-612 and the distance travelled by

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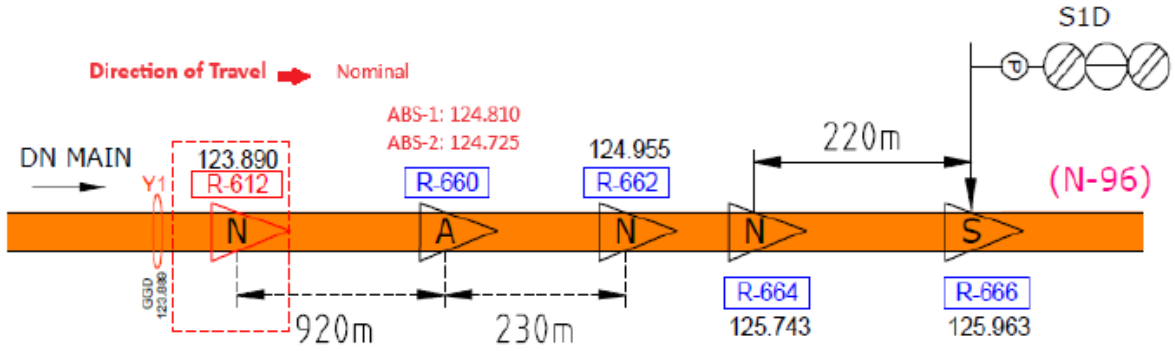

Figure 9. Exit tag placement.

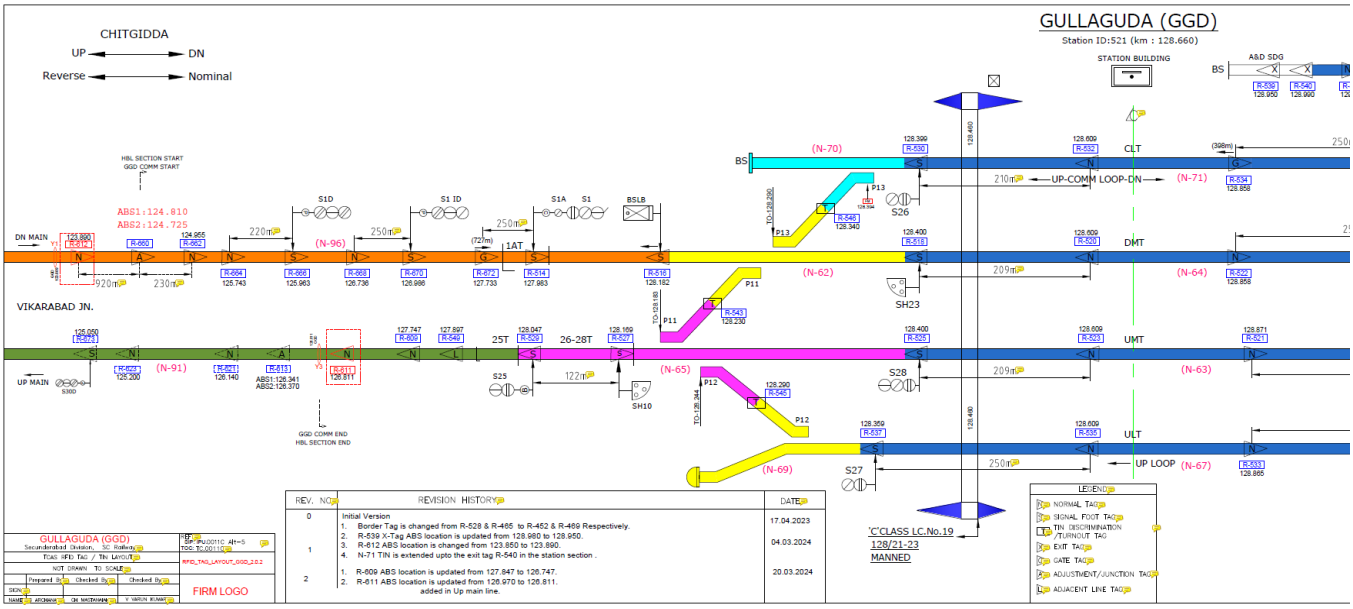

Figure 10. TIN assignment to tracks.

onboard, i.e., 123.890 + 920= 124.810, and ABS-2 is the corrected absolute location of -85 meters & the direction of travel is Nominal to Nominal.

#Level Crossing Gate Tag

LC Gate tags shall be placed at such a distance that Auto whistling for approaching the LC gate can commence from at least 600m or W/L board on the approach of the LC gate.

#Track Identification Number (TIN)

TIN numbers are provided to all the designated tracks as shown in Figure 11. The main features of TIN are as Each track shall have a designated Track Identification Number (TIN). A single TIN section shall be represented using a single color. The TINS in vicinity shall be represented in different colors. Non-KAVACH territory shall be represented through the white color. TINs shall be allotted as per simultaneous movements permitted in the yard. Each Block section shall have a single unique designated TIN. Each berthing portion shall have unique and different TINs.

#RFID data Format

Table 2 below displays the Bit format of RFID data, including bit position and the Number of bits, along with a description of each field**.**

This total information is stored inside each RFID tag installed on the rail sleeper at a distance of 1km approx. Which is then read by the tag reader installed on the locomotive's board. The Movement of authority of the train is decided by the data provided by the RFID data.

#Network Management System

Network Management System (NMS) shall be provided over OFC Network (E1 interface) for centralized monitoring of Kavach-equipped Trains and Stations within the network. It is used for troubleshooting error events, offline simulation, and real-time monitoring of Onboard Kavach, among other purposes. Stationary Kavach and Onboard Kavach transmit exceptional fault/critical messages to NMS. A Central Server is present in the Division Control Room. All relay information and radio packets exchanged between Station and Loco are logged in the Central Server and accessed through NMS.

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Table 2. RFID data Format.

Field	Normal Tag		Description
	Bit Position	No of bits	
Type of Tag (1001: Normal Tag)	X3-X0	4	This field indicates the type of tag. Decimal value is 9
Version	X5-X4	2	0: Kavach Spec 3.2 1: Kavach Spec 4.0 2,3: Reserved for future use
Unique ID of RFID Tag	X15– X6	10	Unique ID of the RFID Tag. Value ranges from 1 to 1023
Absolute Loc in meters (1111111 11111111 11111111 : Not Applicable	X38– X16	23	Geographical location of the RFID Tag in terms of meters as per Railway metrics or the Location referred to in the Signal Interlocking Plan of the respective stations. Value ranges from 0 to 83,88,607
TIN in Nominal Direction	X46 – X39	8	Track Identification number encountered while traversing in Nominal Direction (Incremental direction of absolute location) Value ranges from 0 to 255 0: TIN value to be used at Kavach territory exit in a valid direction
TIN in Reverse Direction	X54– X47	8	Track Identification number encountered while traversing in the Reverse direction (Decremental direction of absolute location). Value ranges from 0 to 255 0: TIN value to be used at Kavach territory exit in a valid direction
Station ID in Nominal Direction	Y6-Y0 & X63- X55	16	Station ID corresponding to Tag placement Note: 0 to be programmed if the Tag is not mapped to any station
Station ID in Reverse Direction	Y22– Y7	16	Station ID corresponding to Tag placement. Note: 0 to be programmed if the Tag is not mapped to any station
Section type in Nominal Direction	Y24 – Y23	2	Indicates whether the territory encountered by the Loco falls in the Station vicinity or Block section in its direction of travel 00-Station Section 01-Absolute block 10-Automatic section 11-Virtual Block (01, 10 and 11 – to be used for collision detection)
Section type in Reverse Direction	Y26 – Y25	2	Indicates whether the territory encountered by the Loco falls in Station vicinity or Block section in its Reverse(74/383) iriset notes direction of travel 00-Station Section 01-Absolute block 10-Automatic section 11-Virtual Block (01, 10 and 11 – to be used for collision detection)
Tag placement	Y30 – Y27	4	Denotes the placement of the tag ''0000'' – In line section ''0001'' – At Signal foot in Nominal direction ''0010'' – At Signal foot in Reverse direction ''0011'' – At Turnout ''0100'' – At Kavach territory exit in Nominal Direction 0101'' – At Kavach territory exit in Reverse direction ''0110'' – At Signal foot in both directions "0111" – At Kavach territory exit in both directions "1000" – At Dead Stop in Nominal Direction "1001" – At Dead Stop in Reverse Direction "1010-1111" Reserved
Tag Duplication	Y31	1	0- Main Tag 1- Duplicate Tag
Communication in Nominal Direction	Y32	1	0- Required 1-Not required
CRC	Y63-Y34	30	Compute CRC (Cyclic Redundancy Checksum) to check the data integrity. 30 Bit CCITT CRC

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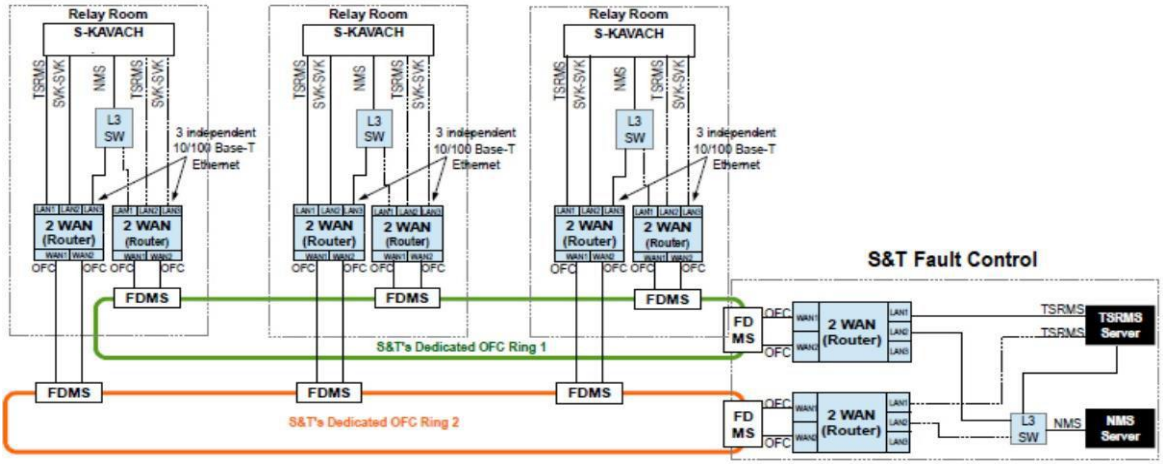

Figure 11. Onboard Kavach to NMS Communication on the GSM interface.

The communication between Onboard Kavach and Network Monitoring System (NMS) shall be through two GSM interfaces provided in the Onboard Kavach Vital Computer. The exceptional fault/critical messages logged by the Onboard Kavach unit are transmitted to the NMS through two GSM interfaces, which are provided in hot standby mode. Onboard Kavach shall log fault messages and transmit to the Network Monitoring System through GSM interfaces in the following cases: In the event of a RFID reader failure (any one or both readers). To indicate the Onboard Kavach mode to NMS through Stationary Kavach Unit on encountering any tag (excluding LC Gate Tag), when the Onboard Kavach unit is in Post, Trip (PT) Mode or Isolation (IS) Mode. In case of missing RFID Tag information received from Stationary Kavach. This, in turn, shall send SMS alert to the Maintenance Staff. Information to NMS if the turn-out tag is over-read by the Onboard Kavach unit. In the event of a Radio Communication failure longer than the applicable time-out (30 Seconds). In the event of a failure of only one radio out of two radios in hot standby. In the event of failure of both GPS/GNSS and Real Time Clock (RTC). In the event of Active Cab/Desk DMI communication failure.

The Salient feature of NMS is summarized below

- Real-time display of train movement on NMS monitors.
- Offline display of train movement on NMS monitors at Normal, 2x, 4x, 8x, 16x & 32x speed.
- Display of Data Log in Spreadsheet (Excel Format).
- Display of "Permitted Speed+ Current Speed Vs Location" and "Permitted Speed and Current Speed V/s Time" including information whether brake command is applied by, Kavach or not in Normal Mode Pseudo Real-time and Offline.
- Ability to watch the NMS at Distant Location through Internet (Password protected)
- Ability to extract offline data log through NMS
- Support branching of the incoming data stream to be forwarded to another port in, interoperable manner
- Generation of Exception Reports - Onboard Kavach Unit-wise, Stationary Kavach Unit-wise, RFID Tag Set-wise.
- Generation of Statistical data such as availability, category-wise braking cases
- Prompt through NMS for missing one of the two RFID tags of same set.
- Prompt through NMS for missing both RFID tags of same set.
- Prompt through NMS for missing communication packets overall below a set level (say 20%) for moving train in the Communication mandatory zone.
- SMS Alert for repeated same RFID tag missing events in Full Supervision Mode.
- SMS Alert for any brake application command by Kavach Loco forcing the train to bring to dead stop in Full Supervision Mode.
- SMS Alert for SPAD.
- SMS Alert for SPAD Prevention by Kavach.
- Optional SMS Alert for Isolation Mode.
- Optional SMS Alert for manually invoking SR Mode.
- Optional SMS Alert for "Communication Failure between NMS and Stationery Kavach" cases.
- Filtering Stations with poor communication based upon missing data communication, packets.
- Filtering Locomotives with poor communication based upon missing data communication, packets.
- Capturing of speed restrictions imposed by the TSR Management System from Stationary Kavach after every update.
- Capturing of health status and event log from Onboard Kavach if LTE is available.

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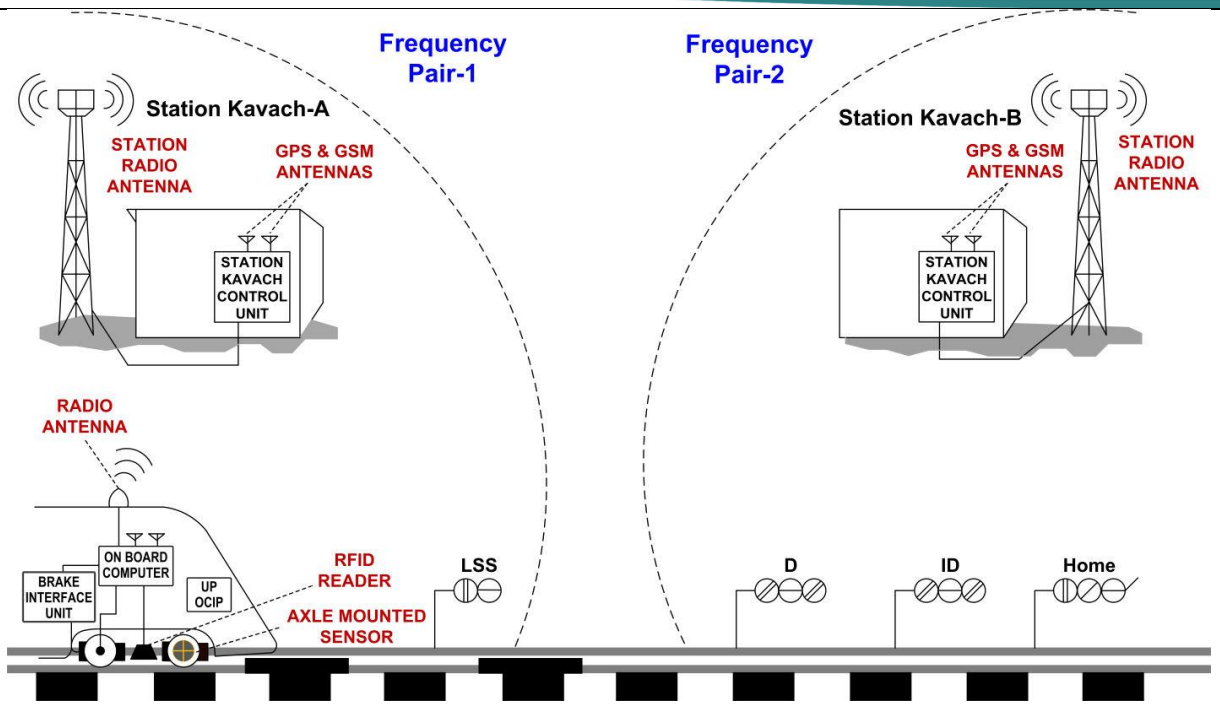

Figure 12. RF Communication arrangement.

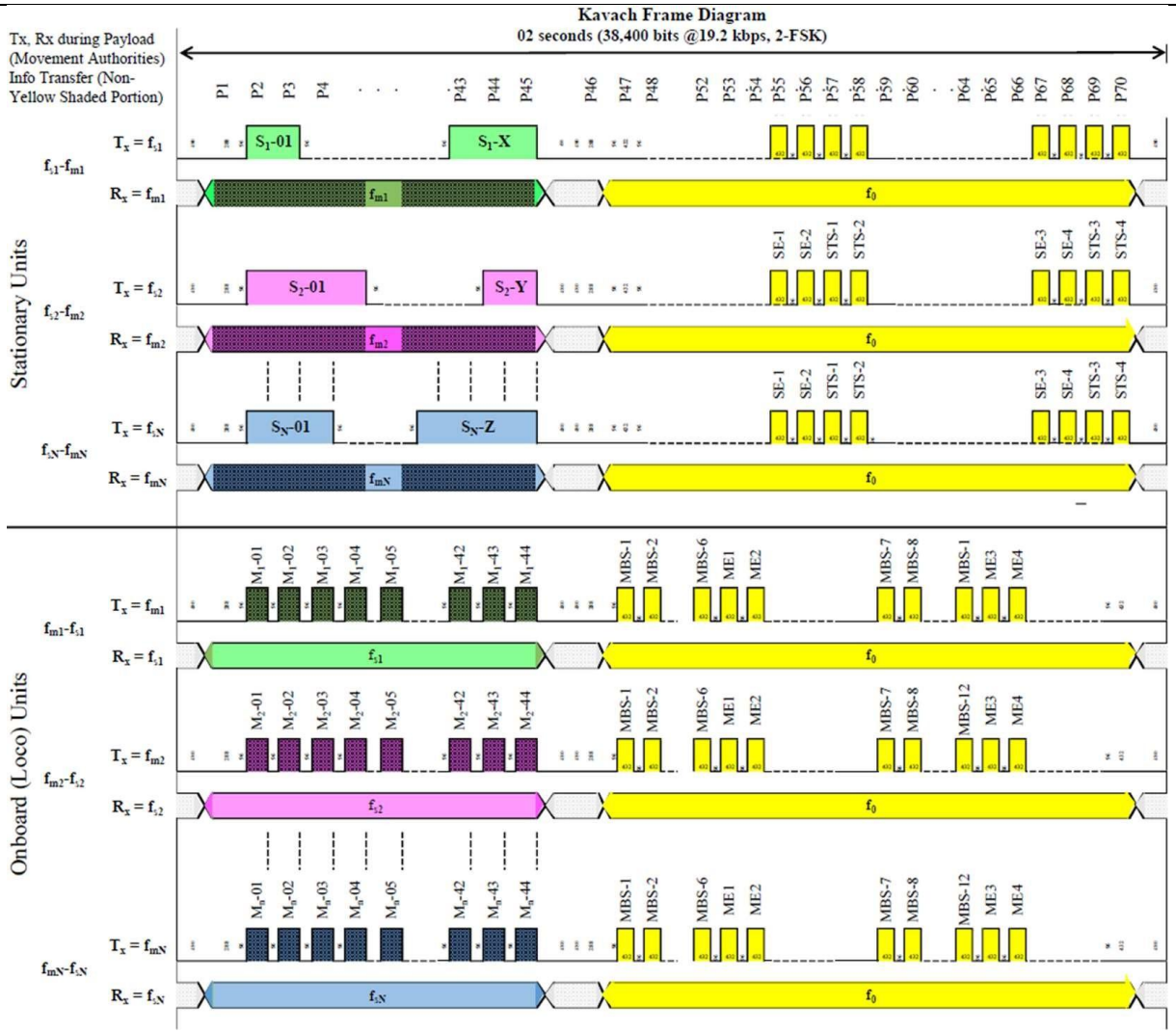

Figure 13. Multiple access technique for TCAS Communication.

#Establishment communication

There are basically three modes of communication in KAVACH system, depending on the Service applications, Radio Communication, GSM/LTE Communication, GPS/GNSS Communication. The Radio communication is used for communication between the Station and the

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Onboard TCAS, as well as between the Onboard TCAS and Other Onboard TCAS units. The radio communication is established using KMS (Key Management Server) through authentication keys over GSM/LTE commercial operator services. NMS is operated using the respective GSM/LTE interface for fault messages from the station to the onboard Kavach. Establishment of RF Communication: Whenever a Loco is in the territory of station TCAS, the station TCAS will allocate a timeslot and a pair of frequency channels (f1 & f2) for such a particular Loco. The Onboard TCAS will continue to transmit over the frequency channel within the allocated time slot, adhering to station limits.

However, in the block sections, the onboard TCAS will operate on centre frequency (f0) in case of emergency situations like SoS, Head-On, or Rear-End Collisions.

The TDMA scheme for full-duplex UHF communication is adopted in TCAS. In the allocated Time slot, both the Stationary and Onboard TCAS will communicate on the designated frequency pair (f1, f2). However, both TCAS will have different TDMA slots. Table 2 below shows the frame cycle with bit size. Figure 14 below shows a Multiple Access scheme for a stationary TCASE. TDMA /FDMA frame will span 2000 milliseconds cyclically. The data size is 38400 bits with a rate of 19.2 kbps with 2-FSK with a frequency range of 406 MHz to 470 MHz. The frame cycle is divided into 70 slots. Each slot is 432 bits (22.5 milliseconds) except positions 1 and 46, which are spaced 96 bits (5 milliseconds) apart. This indicates that between certain slots, there is 96-bit (5 millisecond) spacing to allow for some delay or adjustment. Time slots from P2 -P45 are used for the station to onboard Kavach

Each station is allotted a Block of many Time slots (2000 milliseconds each) used to communicate with Onboard TCAS over a specific pair of frequencies (Fs1-Fm1 for station1). Some specific Time slot in f0 is assigned for emergency services like SOS messages, etc (Figure 14). Such an emergency message shall be received by other trains in the vicinity without relaying through Stationary TCAS.

#GSM/LTE Communication

The Primary purpose of the GSM /LTE communication arrangement used for NMS is to give the following information. The exceptional fault/critical messages logged by Stationary Kavach and Onboard Kavach units are transmitted to NMS through respective GSM/LTE interfaces provided in Hot standby mode. Stationary Kavach shall log fault messages and transmit to Network, Monitoring System in the following cases: Radio Communication failure longer than the applicable time-out, Failure of only one radio out of two radios in hot standby in Onboard Kavach, If the incremental difference between CPU and GPS time does not match, and the. The difference between the two GPS is greater than the frame interval. Failure of both – GPS/GNSS and Real Time Clock (RTC). Active Cab/Desk DMI communication failure in Onboard Kavach. On board Kavach shall log fault messages and transmit them to the Network Management System in following cases:

i. RFID reader failure
ii. In Post Trip (PT) Mode or Isolation (IS) Mode.
iii. On receiving Missing RFID Tag information.
iv. Radio Communication failure longer than applicable time-out (30Seconds).
v. Failure of only one radio out of two radios in hot standby.
vi. Failure of both GPS/GNSS and Real Time Clock (RTC).
vii. Active Cab/Desk DMI communication failure.
viii. In case of Pulse Generator failure
ix. If either or both RFID readers of the Onboard Kavach fail.

Secondary application of GSM/LTE communication is KMS, as shown in Figure 18

#Key Management Server (KMS)

It is designed to share secret Authentication keys to Stationary and Onboard Kavach units. Message origin authentication/ message integrity are safety procedures that ensure the integrity and authenticity of messages during Radiocommunication. These Authentication keys are used to protect the messages against modification and to ensure that no one can masquerade as the originator of the message.

They are shared only after authenticating the Onboard Kavach through OTP. KMS is deployed on a secure server on the Internet. All onboard Kavach units periodically request authentication keys and use them for Radio Communication. GSM/LTE modules located in the Event Logger module are used to connect Onboard Kavach to GPRS (Internet)/LTE networks. KMS is responsible for distributing authentication keys to Kavach systems for radio security. Communication between Stationary and Onboard Kavach Units is based on AES-128 encryption, GSM/LTE communication is used to transfer Keys to Loco and Stationary Kavach.

A central KMS server is hosted to communicate authentication keys to Onboard Kavach and Stationary Kavach. Single KMS is sufficient for all Railways. All the stationary Kavach and Onboard Kavach IDs, as well as SIM card numbers, are to be provided to Railtel for

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updating in the KMS. Communication between KMS and Kavach is on GPRS and currently being upgraded to LTE.

- The factors affecting time synchronization are temperature, inferior quality clocks, resource constraints, high density and node failures. When RTC

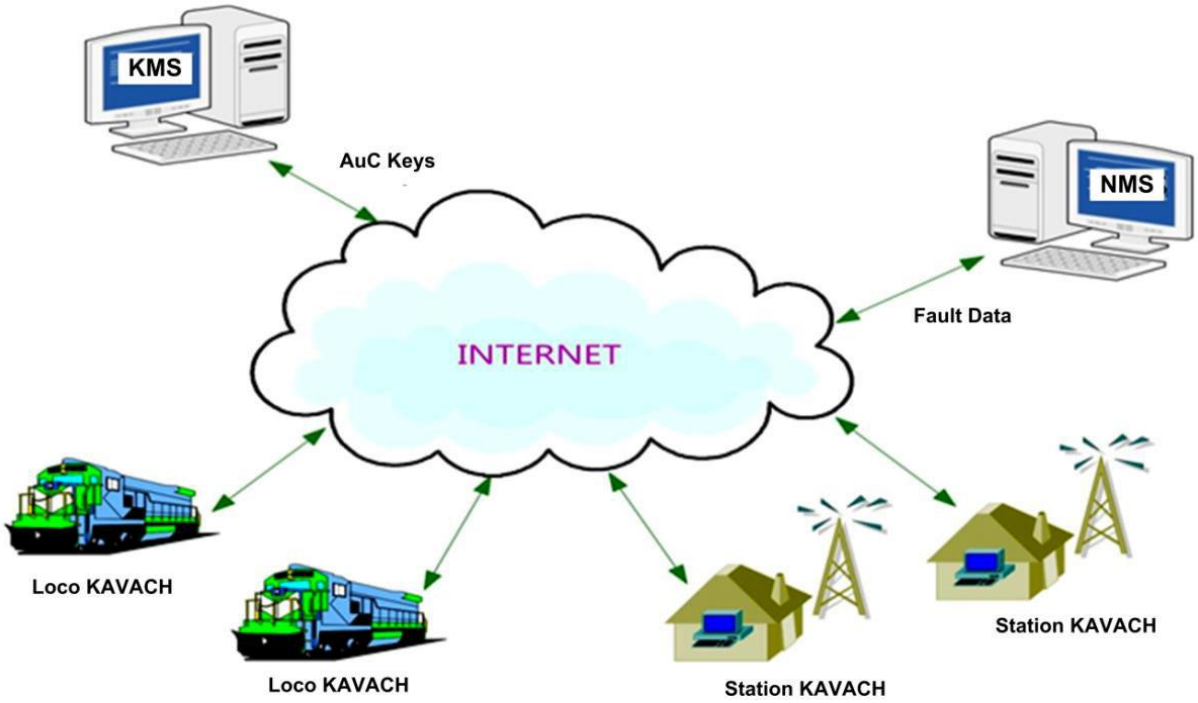

Figure 14. Key Management Server communication.

#GPS/GNSS Communication

Main features of GPS/GNS traffic communication are summarized below

- Time synchronization is very important for seamless data communication among
- various Kavach units. Absence of time synchronization often results in errors/faults.
- Multiple Access TDMA scheme is used in Kavach, which requires a unified time
- Synchronization. We do not have a Universal Time clock in India, hence, we use
- GPS/GNSS Clock to correct the Real Time Clock (RTC) of any system.
- Station/LC/IBS Vital Computer shall have Real Time Clock (RTC) synchronization
- Facility with a GPS/GNSS clock to synchronize with other Kavach systems in a hot-standby manner.
- GPS antenna is installed at the stationary Kavach unit for time synchronization. Two separate antennas for GPS shall be installed using diverse paths for high availability.
- A diverse mix of GPS is preferable to avoid common cause failures.
- The Station/LC/IBS Vital Computer RTC should be synchronized with the RTC of all Onboard Kavach Vital Computers and other Kavach systems. The RTC of all the Kavach units is set with a time reference to GPS/GNSS.

of any Station/LC/IBS

- Kavach or Onboard Kavach does not match the RTC of other Kavach units; it synchronizes with the GPS/GNSS clock.
- When the CPU time of Station/LC/IBS Kavach or Onboard Kavach and the GPS time are not synchronized, the time reference shall change to another GPS.
- If both GPS fail, then the system shall work on CPU time for 30 minutes until the situation is stabilized. If there is no stability after GPS time-out, the Loco shall transit out of Full Supervision Mode to SR mode.

Results and Discussion

The radio communication in TCAS has been upgraded compared with previous technologies like Anticollision Devices and Automatic Warning Systems, due to application of GPS, GSM and local track data from stations TCAS. Both TCAS (Onboard and Stationary) verify CBC -MAC [Cypher Block Chaining (CBC) mode, message authentication code] before processing each message. The onboard TCAS retries Access Request Packets if it does not receive a response within the time. The onboard TCAS continuously sends messages on F0 in the event of a manual SOS or an unusual halt of the train in the block section, without interfering with each other. The results observed on the radio modem are summarized below

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Table 3. Radio Modem Details.

Characteristics	Description
Frequency range	406-470 MHZ
Channel Bandwidth	25 KHz
Modulation Technique	2 FSK
Bit rate	19200 bps
BER	$1x10^{-8}$ at -100 dBm
Adjacent channel Rejection (for Receiver)	70 dB at 25 KHz channel bandwidth
Frequency Stability (For Transmitter)	1.0 ppm
Output Power (For carrier)	1-10 watts
Operation type	Full duplex
Compatibility	RS 232, RS-485
Cable Type used	LMR-400/LMR -600
Antenna Gain	3 d B
Input Impedance	50 Ohms
Radiation Pattern	Omni Directional
Polarization	Vertical
Wind sustainability rating	200 km/hr

The study in the work indicates a leap forward in the development of safer movement of trains and reduces human dependence in the event of emergency brake application. This TCAS technology will prevent SPAD (Signal Passing at Danger), head-on collisions, side collisions, and rear-end collisions.

Conclusion

The survey of TCAS represents technological features of train protection in terms of SPAD and rear-end collision. This technology is also equipped with an SOS facility on a dedicated frequency to handle emergencies. All three modes of wireless communications, viz., GPS, RF and GSM, have been utilized for the overall operation of TCAS. OFC-based communication is preferred for transporting signaling data. Multiplexing Schemes (TDMA/FDMA) have been incorporated into the communication between stations and loco drivers. NMS and KMS have been associated for Remote diagnostics and Key Authentication purposes to avoid unauthorised access. This technology is fulfilling CELNEC /SIL standards for railway safety.

Future scope

Adhoc WSN may be used for fixed railway structures (rail bridge, Tunnel, rail tracks, track beds, OHE mast). Bridges suffer structural defects produced by continuous strains and vibrations due to the passing of trains. Tunnels are prone to damage due to corrosion; however, data. Transmission in tunnels is difficult. Railway track health monitoring, including twists, kinks, and cracks, is crucial as it plays a vital role in ensuring the safe operation of trains. Hence, structural flows are to be monitored using WSN. The rail track bed is also damaged due to poor soil quality, and the pore pressure of water in the subsoil increases as the train repeatedly passes over it. Similarly, monitoring movable structures using WSN may be updated on board the DMI. An on-board sensor can be used to monitor parameters such as temperature, shock, tilt, and humidity. Movable real-time condition monitoring through WSN may be communicated to the train driver for early action. Any damage to the train engine, Carriage, wagons, or containers is monitored using WSN and reported in real-time. Train axle monitoring, such as HABD (hot axle box detection), can be triggered by excessive strain and may lead to total deterioration. This condition can also be detected and communicated to the driver for prompt corrective action. In a railway electrified area, Overhead power lines and Train pantographs require continuous monitoring. Perfect train contact with OHE is required for standard current collection to power the train. Optical sensors, which are immune to EMI, may be used for condition monitoring of the Pantograph and may be provided to the Train driver machine interface with the help of an ad hoc WSN. All condition monitoring data of fixed and movable rail infrastructure may also be relayed to the station control room for further corrective action.

Conflict of interest

The author(s) declare no conflict of interest in the survey carried out in this paper.

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